Correlation between Low-Frequency Fluctuations and Plasma Stored Energy in GAMMA 10

Yoshiaki MIYATA, Masayuki YOSHIKAWA, Fumiaki YAGUCHI, Makoto ICHIMURA, Tatsuya MURAKAMI and Tsuyoshi IMAI

Plasma Research Center, University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan

(Received 14 July 2010 / Accepted 23 July 2010)

The instabilities observed in many magnetic confinement devices induce radial particle transport. Density and potential fluctuations were measured using a gold neutral beam probe in GAMMA 10. The plasma stored energy repeatedly increases and decreases during ion- cyclotron range of frequency heating. A drift-type fluctuation was observed in both the density and the potential as the plasma stored energy decreased. These results indicated a correlation between the radial particle transport induced by drift-type fluctuations and decreasing plasma stored energy.

Keywords: gold neutral beam probe, drift-type fluctuation, potential fluctuation, density fluctuation, radial particle transport

DOI: 10.1585/pfr.5.033

In magnetically confined plasmas, particle and energy confinement are important because particle transport decreases the density and temperature. The plasma particles escape across the confinement magnetic field as a result of fluctuations due to instabilities in the plasma, which cause fluctuations that lead to the transport [1]. Drift waves, called universal instability, have been observed in many devices because of the plasma density gradient [2–4]. Therefore, it is important to study the mechanisms of particle transport due to fluctuations. In this paper, we present a correlation between low-frequency fluctuations and the plasma stored energy in the GAMMA 10 tandem mirror.

Experiments were conducted in the GAMMA 10 tandem mirror. The lengths of the central, anchor, and plug/barrier cells are 6.0, 4.8, and 2.5 m, respectively. The magnetic field strength at the mid-plane of the central cell is 0.41 T in standard operation. The plasma is produced by plasma guns and is heated and sustained using ion cyclotron range of frequency (ICRF) heating systems. The plug/barrier cells are located at both ends of GAMMA 10, where the ion and electron axial confinement potentials are produced by electron cyclotron resonance heating.

Density and potential fluctuations are measured by a gold neutral beam probe (GNBP) system [5–7]. The probe beam is neutral gold particles. The energy and incident angle of the primary beam passing the plasma center are about 12 keV and 40° to the horizontal direction, respectively. A typical primary beam current of 2 μA is confirmed from a Faraday cup measurement. A parallel-plate- type electrostatic energy analyzer with an incident angle of 45° to the ground plate is installed. In the analyzer, a micro-channel plate detector with 32 anodes detects the secondary beam. The detected positive secondary beam is derived from the neutral primary beam ionized by electron- impact at an arbitrary ionization position. Information about the density fluctuations is obtained from the perturbation of the detected beam intensity. It is possible to measure the density and potential fluctuations and their phase difference at the arbitrary point simultaneously by the GNBP. Small fluctuations cause local transport. If the potential and density fluctuations are measured, the radial particle flux can be derived experimentally. The radial particle flux related value due to the electrostatic fluctuation is defined as $\gamma_{n\phi}\tilde{I}/I\tilde{\phi}\sin\alpha_{n\phi}$ [8]. Here, $\gamma_{n\phi}$, $\tilde{I}$, $\tilde{\phi}$, and $\alpha_{n\phi}$ are coherence, density fluctuation, potential fluctuation, and the phase difference between them, respectively.

After the plasma is initiated with both sides of the plasma gun, ICRF heating systems are used in the central cell. Figure 1 shows the line- integrated electron density and diamagnetism in the central cell. The diamagnetism indicates the plasma stored energy. The line- integrated electron density fluctuated substantially at 122, 130, 138, and 145 ms, and the diamagnetism decreased at the same time. The diamagnetism repeatedly increases and decreases during the ICRF heating period. The density and potential fluctuations were measured at $R \sim 0.01$ m using a GNBP. Figures 2 (a) and 2(b) show contour plots of the frequency spectra of the density and potential fluctuation levels, respectively, obtained by time-frequency analysis. Low-frequency fluctuations occurred periodically. The observed fluctuations are estimated to be drift-type fluctuations with the azimuthal mode number of 2 by an electrostatic probe array. This drift-type fluctuation grew as the frequency increased from 11 to 12 kHz because the diamagnetic drift velocity changed. Figures 3 (a), 3 (b), 3 (c),

author's e-mail: miyata@prc.tsukuba.ac.jp

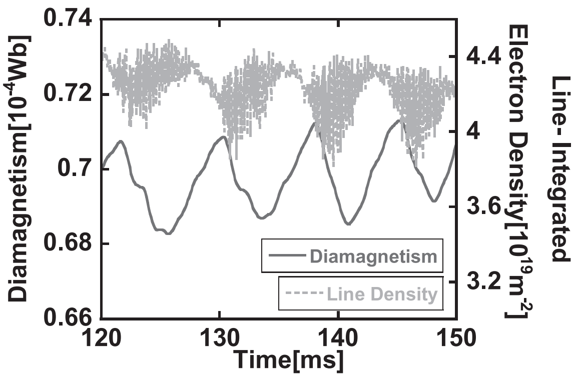

Fig. 1 Time evolution of the line- integrated electron density and diamagnetism in the central cell.

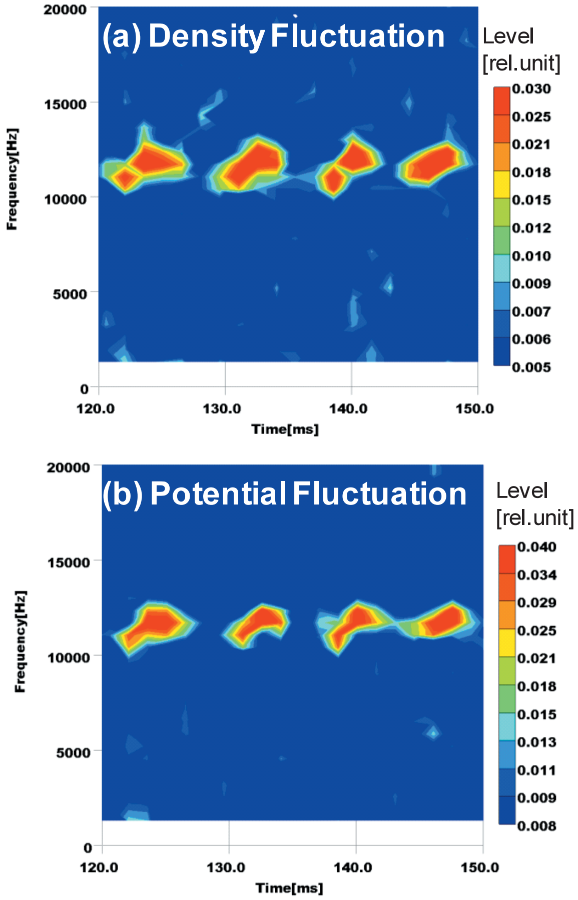

Fig. 2 Contour plots of frequency spectra of (a) density fluctuation level and (b) potential fluctuation level.

and 3(d) show the time evolution of the density and potential fluctuations levels, cross phase, coherence, and radial particle flux due to drift-type fluctuations, respectively. Each spectrum was analyzed within a time window containing 512 data points with a sampling rate of 3 μs.

In Fig. 3 (a), the solid and dotted curves correspond to the density and potential fluctuation levels, respectively. The time evolutions of the density and potential fluctuation levels show the same tendency. The cross phase and coherence between them are almost 0.6 and 0.9, respectively. Because the direction of radial particle flux depends on the cross phase, the radial particle flux occurred in the same direction in Fig. 3 (d). The radial particle flux was inversely proportional to the diamagnetism. The fluctuations were nonlinearly damped, and the diamagnetism was increased again by ICRF heating.

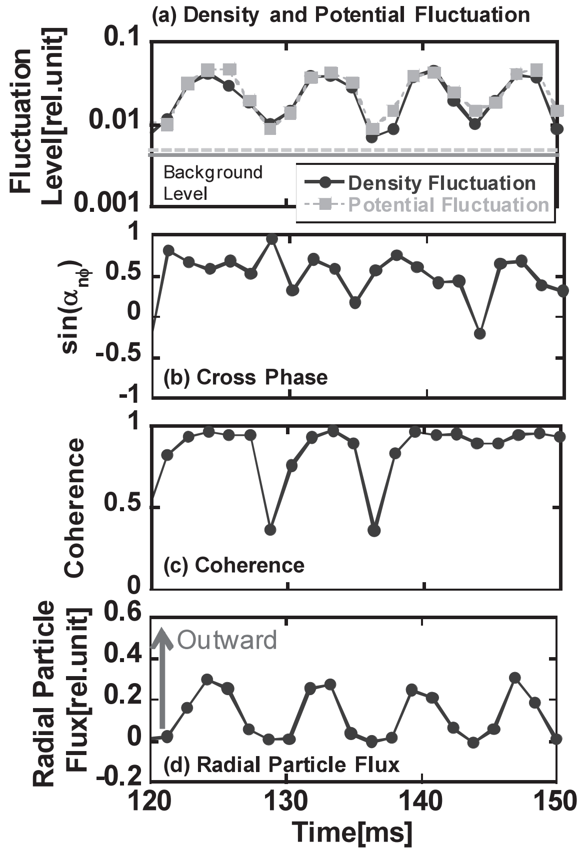

Fig. 3 Time evolution of (a) density and potential fluctuation levels, (b) cross phase, (c) coherence, and (d) radial particle flux due to drift-type fluctuations.

In summary, density and potential fluctuations were measured using a GNBP in GAMMA 10. The diamagnetism repeatedly increased and decreased during the ICRF heating period. These results indicate a correlation between the radial particle transport induced by drift-type fluctuations and decreasing plasma stored energy. This phenomenon is estimated to be the theoretically- predicted loss process induced by radial particle transport due to the phase difference between the potential and density fluctuations.

The authors thank the members of the GAMMA 10 group of the University of Tsukuba for their collaboration. This study was partly supported by a Grant-in-Aid for Young Scientists (B), No. 22740359. This study was conducted with the support and under the auspices of the NIFS Collaborative Research Program, NIFS04KUGM009.

[1] B. Fischer *et al.*, Plasma Phys. Control. Fusion **31**, 453 (1989).
[2] H.W. Hendel *et al.*, Phys. Rev. Lett. **18**, 439 (1967).
[3] H.W. Hendel *et al.*, Phys. Fluids **11**, 2426 (1968).
[4] W. Horton, Rev. Mod. Phys. **71**, 735 (1999).
[5] Y. Miyata *et al.*, Trans. Fusion. Tech. **55**, 168 (2009).
[6] Y. Miyata *et al.*, J. Plasma Fusion Res. **2**, S1101 (2007).
[7] Y. Miyata *et al.*, Rev. Sci. Instrum. **79**, 10F308 (2008).
[8] A. Kojima *et al.*, Fusion Sci. Tech. **51**, 2T, 274 (2007).